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PLATE TECTONICS

Objective:	To study the tectonic processes and topographic features associated with plate boundaries.
Reference:	McKnight and Hess, *Physical Geography*, 8th ed., pp. 383–393.

PLATE TECTONICS

The model of **plate tectonics** is the starting point for understanding the distribution and formation of many collections of landforms around the world. Figure 1 is a map showing the principal plates and plate boundaries. These **lithospheric plates** are 65 to 100 kilometers (40 to 60 miles) thick and consist of the crust and upper mantle. The plates move over the layer of the mantle known as the **asthenosphere** at speeds averaging from 2.5 to 10 centimeters (1 to 4 inches) per year.

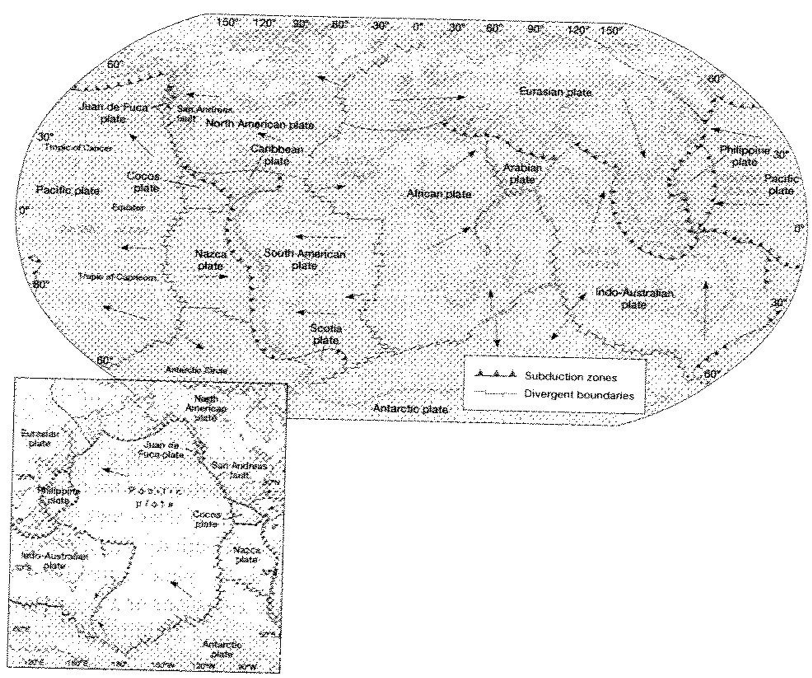


Figure 1: Major lithosphere plates. Barbed lines show collision; lines with offsets show spreading; single lines show transform boundaries; arrows indicate generalized direction of plate movement. (From McKnight and Hess, *Physical Geography*, 8th ed.)

PLATE BOUNDARIES

The three different kinds of plate boundaries are associated with different kinds of topographic features and tectonic activity.

Divergent Boundaries: At divergent boundaries (also called **spreading centers**), plates are moving apart. The most common kind of spreading center is the **midocean ridge** where new basaltic ocean floor is created (Figure 2). Spreading may also take place within a continent. In this case, blocks of crust may drop down as the land is pulled apart, producing a continental **rift valley**.

Convergent Boundaries: At convergent boundaries, where plates collide, three circumstances are possible:

1. If the edge of an oceanic plate collides with the edge of a continental plate, the denser oceanic plate is **subducted** below the continent, producing a deep ocean trench. As the oceanic lithosphere descends, heat drives off water and other volatile matter from the ocean rocks, leading to the partial melting of the mantle. The **magma** that is generated rises, producing intrusions of **plutonic rock** such as granite and a chain of andesitic **volcanoes**, such as the Andes in South America or the Cascades in North America (Figure 2).

2. If the edge of an oceanic plate collides with the edge of another oceanic plate, subduction also takes place. A deep **oceanic trench** forms, along with a chain of andesitic volcanic islands known as an **island arc**, such as the Aleutian Islands in Alaska.

3. If the edge of a continent collides with the edge of another continent, the relatively buoyant continental material is not subducted. Instead, a mountain range is uplifted. The Himalayas are a dramatic example of this kind of plate boundary interaction.

Transform Boundaries: Plates slide past each other at transform boundaries, such as a long the San Andreas fault system in California (Figure 3).

EVIDENCE OF PLATE TECTONICS

Evidence supporting the theory of plate tectonics comes from global patterns of landforms and tectonic activity. In addition to the matching shape of the continental margins on both sides of the Atlantic Ocean (which spread apart from the Mid-Atlantic Ridge), the age of the ocean floor provides evidence of movement. The ocean floors are youngest at midocean ridges, where new lithosphere is being formed, and become progressively older away from a ridge in both directions. This was verified through ocean core samples, as well as **geomagnetic** evidence (changes in the Earth's magnetic field that have been recorded in the volcanic rocks of the ocean floor).

Plate boundaries are often the sites of significant volcanic activity. At spreading centers, magma is moving up to the surface, creating new lithosphere as the plates spread apart. Magma generated in subduction zones can produce a chain of continental volcanoes or a volcanic island arc.

The distribution of **earthquakes** also provides clues to plate activity. Most earthquakes around the world occur in association with plate boundaries. Shallow-focus earthquakes, within about 70 kilometers (45 miles) of the surface, occur at all plate boundaries. However, in subduction zones, bands of progressively deeper earthquakes are observed, produced when an oceanic plate is thrust down into the mantle.

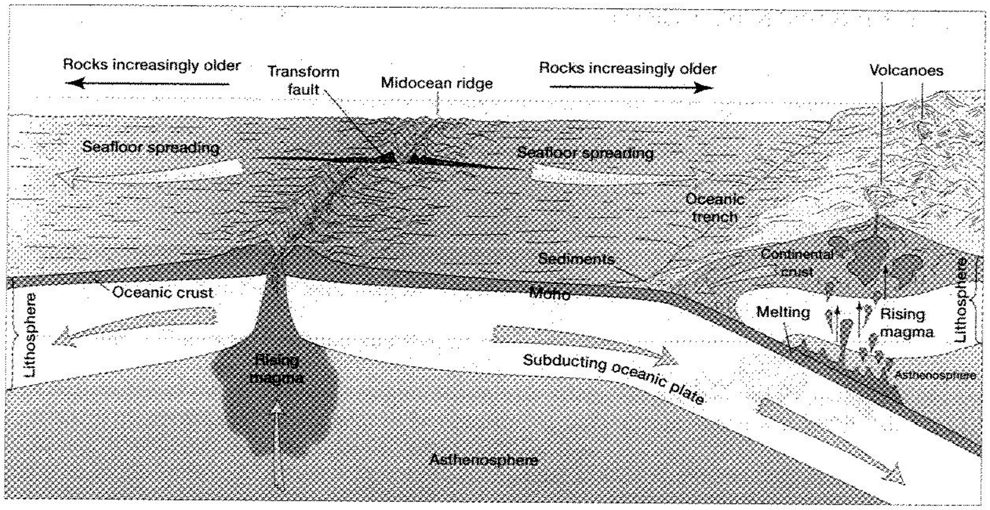


Figure 2: Plates move apart at spreading centers such as midocean ridges, collide at convergent boundaries such as subduction zones, and slide past each other along transform faults. (From McKnight and Hess, *Physical Geography*, 8th ed.)

MANTLE PLUMES

One of the important modifications of basic plate tectonic theory is the concept of the **mantle plume** or **hot spot**. These are locations where a fairly narrow plume of magma is rising from the asthenosphere to the surface, producing volcanoes.

Mantle plumes may occur well away from plate boundaries, often in the middle of a plate. It is not yet completely understood why these hot spots occur where they do, but the existence of mantle plumes has been helpful in verifying plate motion.

Evidently, mantle plumes can remain active in the same location for millions of years. While the mantle plume remains in the same place, the plate above continues to move over it. Currently active volcanoes are found directly over the mantle plume, while the moving plate carries older volcanoes off the plume, at which time they become inactive. Ongoing plate motion carries these old volcanoes farther and farther away from the plume, resulting in a chain of extinct volcanoes.

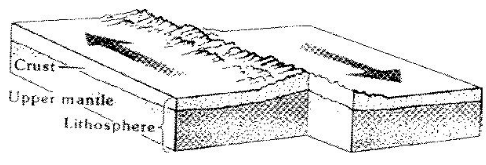


Figure 3: Transform plate boundary. (From U.S. Geological Survey Bulletin 1595)

THE HAWAIIAN HOT SPOT

The Hawaiian Islands are the best-known example of an island chain produced by a mantle plume. The only currently active volcanoes are found on the island of Hawaii in the southeast part of the island chain. It is believed that this island is currently over the hot spot.

Figure 4 is a map showing the ages of volcanic rocks in the Hawaiian chain. Notice that the age of the volcanic rocks becomes progressively older as we follow the islands to the northwest. The pattern of islands in the Hawaiian chain shows the general direction of movement of the Pacific Plate, and from the ages of the rocks, we can infer the rate of plate movement.

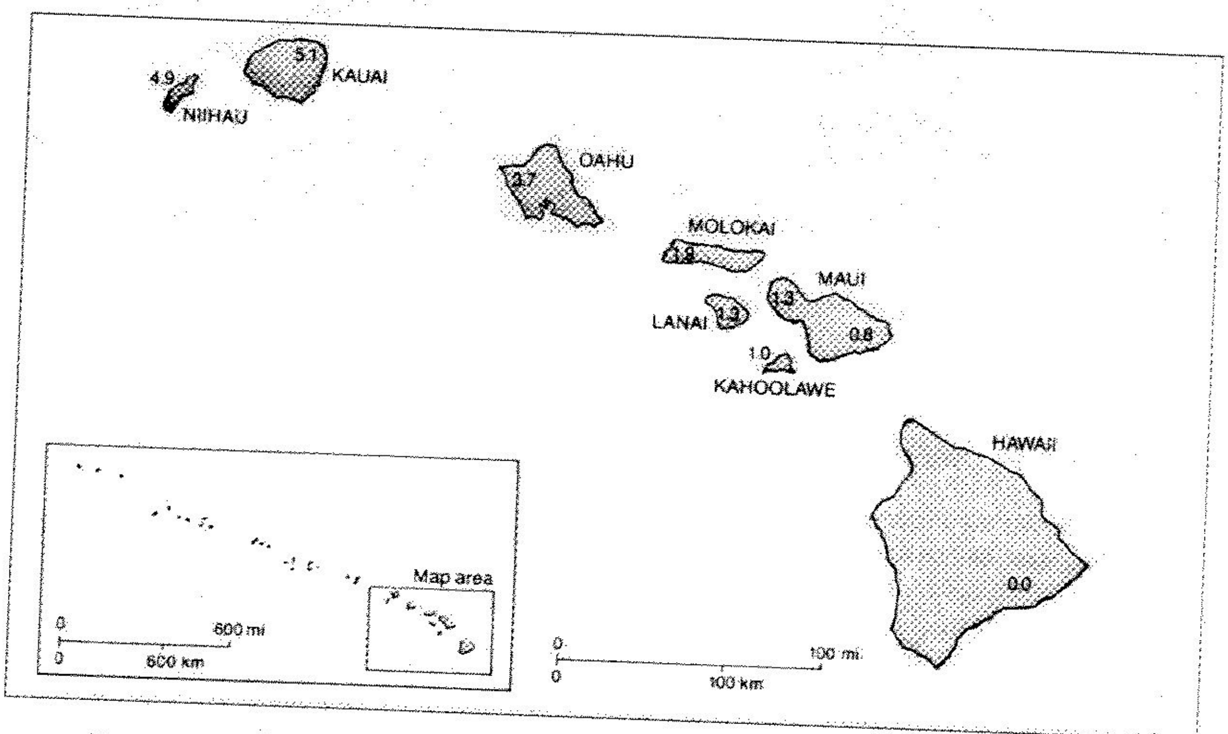


Figure 4: The Hawaiian Islands. The ages of the basalt from the Hawaiian volcanoes are shown in millions of years; map scale 1:4,200,000. (Adapted from McKnight, *Physical Geography*, 4th ed.)

PROBLEMS – Part I

In the problems for this exercise, you will study the tectonic map of a hypothetical ocean basin. The map shows the location of volcanoes, earthquakes, and the age of ocean floor rocks. From this map, you will determine the probable location of the plate boundaries and the locations of major topographic features in the region.

On the map, the edges of two continents are shown (in the upper right corner and the lower left corner). Six islands are also shown in the ocean basin.

The symbols used on the tectonic map are described below.

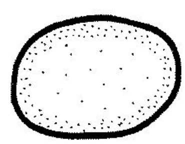
Earthquake Epicenter Location and Depth:

The locations of earthquake epicenters are shown with letters. The depth of an earthquake (the distance of the **earthquake hypocenter** or **focus** below the surface) is indicated with an "S" (shallow focus), "I" (intermediate focus), or "D" (deep focus):

S	=	Shallow Earthquakes	0–70 kilometers (0–45 miles) deep
I	=	Intermediate Earthquakes	70–200 kilometers (45–125 miles) deep
D	=	Deep Earthquakes	200–500 kilometers (125–310 miles) deep

Active Volcano: ▲

Continent or Island:



Age of Volcanic Ocean Floor Rocks:

The circled numbers represent the age of volcanic ocean floor rocks in millions of years.

For example, ⑳ indicates the location of 20 million year old rocks.

EXERCISE PROCEDURE:

The first step of the exercise is to draw in the approximate plate boundaries as indicated by the tectonic activity on the map.

Clues include:

(a) The pattern of earthquakes. For example, subduction produces a pattern of deeper and deeper earthquakes as one plate plunges below the other.

(b) The age pattern of volcanic ocean floor rocks suggests the location where new ocean floor is being created at a midocean ridge.

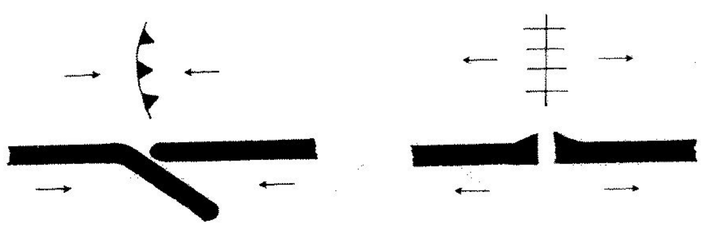
(c) Volcanic activity may be associated with subduction, spreading centers, or mantle plumes.

Use the following symbols to indicate the extent of all plate boundaries. Both the map symbols, and a side view of the circumstance they represent, are shown below. Arrows indicate direction of plate movement.

Convergent Boundary (Subduction) — Divergent Boundary

Map Symbol To Be Used:

Side View:



Note:

- No transform boundaries are found on the map.
- Assume that only one of the volcanoes on the map has been produced by a mantle plume.

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PROBLEMS—PART II

Using the map of the Hawaiian Islands and the ages of the basaltic lava (Figure 4), compute the approximate rate of movement of the Pacific Plate as it passes over the Hawaiian hot spot.

You will compare the age and distance between several different volcanoes on the islands. The ages of volcanic rocks on the islands are given in millions of years. Assume that the decimal point of an age marks the location of a volcano. For example, on the island of Hawaii, "0.0" marks the location of the currently active volcano, Kilauea.

In this exercise, you will compare Hawaii (0.0 years—currently active volcanoes), Molokai (1.9 million years), Oahu (3.7 million years) and Kauai (5.1 million years). For the purposes of this exercise, we will take the position of the Kilauea volcano to represent the location of the Hawaiian hot spot. (Keep in mind that this is a simplistic assumption.)

1. Complete the chart on the following page:

   (a) First, determine the distance between each pair of locations listed on the chart. With a ruler, carefully measure the distance between locations on the map to the nearest millimeter if you use S.I. units and to the nearest 1/16 inch if you use English units. (If you use English units, convert fractions of inches to decimals to make other calculations easier.) This figure is the "Measured Distance On Map." Then multiply this measured distance on the map by 4,200,000 (the denominator of the fractional map scale) to determine the "Actual Distance" in millimeters (or inches).

   (b) Next, determine the "Age Difference" in years between each pair of locations. (Be sure to include the correct number of zeros in your figure.)

   (c) Finally, divide the "Actual Distance" between locations by the "Age Difference" to estimate the rate of plate movement in millimeters (or inches) per year.

Locations	Measured Distance on Map (in mm or inches)	Actual Distance (in mm or inches)	Age Difference (in years)	Rate of Plate Movement (mm or inches per year)
Kauai to Hawaii				
Oahu to Hawaii				
Molokai to Hawaii				
Kauai to Oahu				
Kauai to Molokai				

2. Based on the average of your five answers in Problem #1 above, what has been the approximate rate of movement of the Pacific Plate in the area of the Hawaiian Islands over the last 5.1 million years?

3. Midway Island, to the northwest of Hawaii, is also part of the Hawaiian chain and is believed to have been produced by the same hot spot. Midway is about 2430 kilometers (1510 miles) from the Kilauea volcano on Hawaii. Use the average rate of plate movement you calculated in Problem #2 above to estimate the age of volcanic rocks you would expect to find on Midway Island.

4. The actual age of the volcanic rock on Midway is about 27.7 million years. Suggest a reason why your answer for Problem #3 above differs noticeably from this.